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REFLECTION FROM, AND TRANSMISSION THROUGH, ROUGH SURFACES.

DISSERTATION

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ARTHUR FEDDEMAN GORTON.

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Reflection from, and Transmission through, Rough Surfaces.

Introduction.

It is a matter of common knowledge that matt surfaces, such as ground glass, smoked glass, paper and plaster-of-Paris, which scatter in all directions the light that falls upon them, behave like polished surfaces when viewed at grazing incidence. According to the theory usually advanced in explaining this action, if the light scattered in a given direction by the elevated portions of the surface differs in phase from that returned in the same direction by the hollows or pits in the surface by a quantity small in comparison to $\frac{\lambda}{2}$, the light may be regarded as regularly reflected (though this is only a manner of speaking). The light thus reflected will be diminished in intensity, depending on the magnitude of the phase difference.

Lord Rayleigh * showed this experimentally by sending light from a Welsbach lamp upon a thermo-couple after reflection from two parallel plates of silvered ground glass. A third ground and silvered plate was found to reflect as much energy as a polished silvered mirror. This experiment is in a sense qualitative, for it does

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*Nature, 64, p. 385, 1901.

not tell with what intensity the individual wave-lengths are reflected.

A study of rough surface reflection has been made recently by Meyer*, but his experiments also may be looked upon as qualitative in the sense referred to above. He employed a rather interesting scheme for showing that rough surfaces reflect like mirrors for sufficiently long waves. Light scattered by the matt surface was received by a concave mirror and "focused" on the slit of a fluorite prism spectrometer, which threw approximately monochromatic light on a thermocouple. By rotating the concave mirror, the blurred image could be gradually thrown off the slit, first in one direction, then in the other. Curves of the type shown in Fig.I were obtained. Curve I is for a polished mirror of the same material, showing a sharp decrease in intensity (J) as the image is shifted by rotating the concave mirror (through the angle α). The dotted curve was obtained with the matt surface, using wave-length 8μ. Curve II is for 5μ, and III for 2μ.

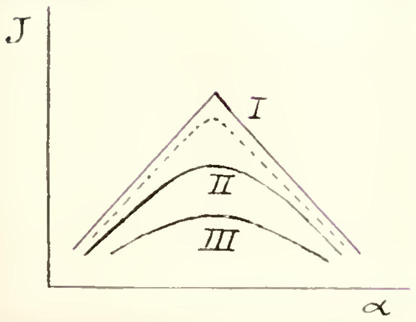

Fig. I.

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* T. J. Meyer, Ber. d. Deutsch. Phys. Ges. p. 126, Feb. 1914.

In other words, waves longer than 8μ are regularly reflected and therefore sharply focused on the slit; while the shorter waves form a broad, diffuse image.

Though Meyer's experiments tell us how a surface of a certain degree of roughness behaves towards waves of different lengths, the method is not directly designed to show the reflecting power of such a surface throughout the spectrum. The experiments described in the following pages were undertaken with the idea of ascertaining the reflecting power, for the range of wave-lengths .6μ to 14μ, of matt surfaces which can be easily and quickly prepared (e.g., ground glass and smoked glass), and thereby showing how well such surfaces are fitted to act as screens for cutting off the short waves. Not only reflection, but also transmission experiments (using roughened plates of rock salt) were performed. It is not necessary to remark that a reflection "screen" is preferable to a transmission cell because it is good for an unlimited range of wave-lengths in the infra-red, whereas rock salt and other so-called "transparent" substances possess regions of opacity.

Apparatus.

The general arrangement of the apparatus is shown in the accompanying diagram.

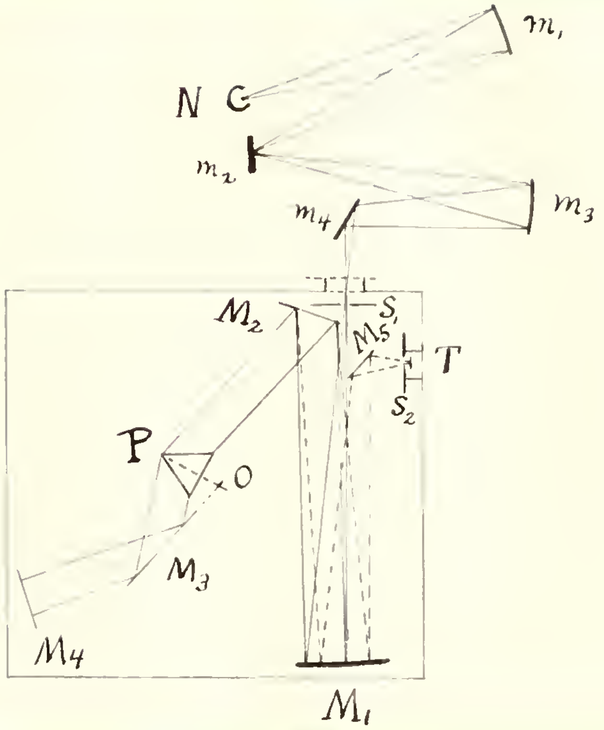

Fig. 2.

The source of light was a Nernst glower (N) suitably protected from air currents by a metal cover. The glower was supplied with current by a 110-volt storage battery, and the constancy of the radiations from the glower was found to be ample for the short period of time (5 minutes or less) required to take readings,at a definite wave-length, with both the rough and the polished mirrors. The light

was focused by a concave silvered mirror m_1 (7.5 cms. in diameter and 26 cms. focal length) upon the rough surface m_2, whence the light was received by m_3 (a duplicate of m_1) and focused on the first slit S_1 of the spectrometer. Although the diagram shows the arrangement for throwing a converging beam of light on the rough surface, all the earlier experiments were performed using strictly parallel light. In both cases the spectrometer receives that proportion of the light which is scattered by the rough surface at the same angle (angle of incidence = angle of reflection) as that at which light is regularly reflected by a polished mirror; - and in all the work to be described it is this which is meant by the "reflecting power" of the matt surface.

The Spectrometer:

The spectrometer was of the usual type, consisting of a rock salt prism P (area of faces 5 x 9 cms.), mounted with the plane silver mirror M_3 according to Wadsworth's arrangement for minimum deviation on a prism table whose axis of rotation passed through C. The table was turned by means of the device used by Mendenhall * - a micrometer arrangement (not shown in the drawing) by which angular displacement of 1/10 second could be accurately read. The concave mirror M_1 (the

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* Astrophysical Journal XXIV, 1, July 1906, p. 22.

only one used in the spectrometer) was of speculum metal, of 10 cms. aperture and 58 cms. focal length, figured by Brashear.

Since infra-red spectrometers have been so often described, the writer wishes to avoid going into details, but feels, nevertheless, that there are a few points of interest in the design which merit consideration.

(1). Definition:-

It is customary to reflect the incident light at a rather large angle ($15^\circ-20^\circ$) from the concave mirror to the prism. The resulting astigmatism blurs the image of the light on the second slit, so that the spectral lines are far from sharp. The writer found that by introducing the extra plane mirror M_2 very close to Slit S_1, thus diminishing the angle of reflection to $2.^\circ 5$ or less, this astigmatism could be very largely done away with. The image of S_1 (using sodium light) received on S_2 was a perfect rectangle. This improvement in the definition of the image was considered to outweigh by far the trifling loss of energy involved in the two extra reflections thus introduced (4 to 10%).

(2) Resolving Power:-

With the idea of doubling the dispersion and the resolving power, it was decided to return the light through the prism, so that the same effect was obtained as from two prisms in series.

This was accomplished by inserting the plane silvered mirror M_4, which received the light from M_3 and returned it over approximately the same path, so as to reach the thermo-couple by way of M_1 and M_5. The edge of M_5 was beveled, so that the angle between the incident and return beams was as small as 2^0. This slight departure from the strict conditions for minimum deviation caused no appreciable shift in the spectrum, as shown by the observed positions of the CO_2 emission bands (2.7μ and 4.4μ), the bands of metallic reflection of quartz (8.5μ and 9μ), and the Iceland Spar band (6.7μ) agreeing with the calculated positions.

The advantages of using this combination Wadsworth-Littrow mounting are several: it yields double the resolving power afforded by a single passage of the light through the prism, giving at the same time ~~four time~~ four times as much energy as the ordinary type of spectrometer with double the focal length (i.e. for a prism of given size); it involves the use of only one concave mirror, which, however, must be carefully figured; and it permits of an extremely compact spectrometer.

The accompanying curve for the transmission of pure (ethyl) alcohol (see Plate I) is given as an example of the resolving power of this instrument. The transmission of a film.01 mm. thick, as obtained by Coblentz, is given on the same plate Plate II for comparison purposes.

It will be observed that there are three small absorption bands between 2μ and 3μ, and perhaps five from 4μ to 6μ, while the great band at 3.5μ is plainly double, one component being at 3.3μ and the other at 3.65μ(see insert in Plate I). Coblentz's curve gives indications of most of the small absorption bands appearing in the region 4μ to 6μ, but not of the others observed.

3. Accuracy of Readings:

From one point of view, the accuracy of the observations is fixed largely by the sensitiveness and the steadiness of the measuring instrument. The thermo-couple was a three- junction compensated instrument, of bismuth-tin alloy and the galvanometer was of the D'Arsonval type with a silver wire suspension. Both instruments were constructed by Dr. A. H. Pfund*. The thermo-couple-galvanometer system had a sensibility of 150 cms. scale deflection for a candle at one meter. Throughout the work no trouble at all was experienced with the galvanometer, which was not magnetically shielded. Over periods of time as long as from fifteen to thirty minutes the zero was constant to within one-tenth of a millimeter, and at all times readings could be repeated to .1 to .3 mm.(even though such accuracy was not needed, in view of the larger experimental errors inherent in the method

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* Phys. Zeit. 13, 1912, p. 870; Phys. Rev. 34, 1912, p. 228.

employed). In view of the rather long scale distance (4 meters) this steadiness was very gratifying.

In this connection, it should be said that the thermo-couple was well protected from stray radiation by enclosing the whole spectrometer (the thermo-couple being fastened rigidly to slit S_2) in an air-tight case of galvanized iron. After the initital adjustment for minimum deviation, the spectrometer was permanently closed, so that it was open to the air of the room only while readings were being taken (i.e. for intervals of 30 seconds). By means of drying agents the moisture was removed from the air surrounding the prism,-so effectively that after three months neither the prism nor any of the mirrors showed signs of deterioration.

Method of Making Observations.

Throughout the work the procedure adopted was as follows. The spectrometer was set for the desired wave-length, and the galvanometer deflection using the rough surface was noted, then the deflection obtained with a polished plane mirror of the same substance. The ratio of the two deflections is what is meant by the reflecting power of the surface in question. By this method, although a laborious one, values were obtained which could be repeated to an accuracy of about 1% beyond 8μ and less than 1% for the shorter waves; and the constancy of the source of light could easily be relied

on for such a short time (2.5 to 5 minutes), so that one annoying source of error was eliminated. It should be said that the surface to be investigated was pressed by a spring against three screws, by means of which one mirror could be exactly replaced by another. Although it was possible to measure reflecting powers absolutely, by rotating the glower and m_1 through such an angle that the light traveled directly from m_1 to m_3 (see Fig. 3), yet this scheme is beset with so many sources of error that it was seldom used. (This is similar to the method employed by Rubens in determining the reflecting power of metals in the infra-red.) A direct determination of the reflecting power of the silver mirror used in Part II was made afterwards, and the observed reflecting powers relative to the silver multiplied by this percentage, so that all the curves for glass, quartz and Iceland spar are in absolute measure.

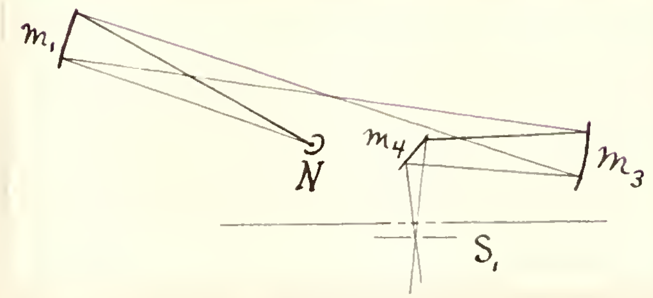

Fig. 3

Results.

Part I. Rough Surfaces as Color Screens for Use in the Infra-Red.

The employment of reflection from rough surfaces as an ideal way of eliminating all the waves shorter than a certain wave-length and leaving the longer waves with nearly their original intensity was first suggested by Lord Rayleigh * . Just what type of matt surface is best adapted to do this is a question to be decided by experiment, for it must be realized that the simple theory given above (page I) applies only to an ideal case, - a surface possessing flat-topped humps all of the same height and uniformly distributed. Such a surface is nearly realized in an ordinary grating, used with its grooves horizontal. Here we are dealing with a beam of light reflected part from the upper portions of the groove, the rest from the lower portions, and interference will cause a certain diminution in the intensity of the light reflected from such a surface. The condition for a minimum of intensity is

$$2\ H \cos i = \lambda \qquad (1)$$

where H = depth of groove, i = angle of incidence.

A secondary minimum will occur if

$$2\ H \cos i = \frac{\lambda}{2} \qquad (2)$$

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* Lord Rayleigh, loc. cit.

in which case the intensity of the light reflected should be 25%. The writer used a small plane grating, of 7000 lines to the inch, ruled by Dr. J. A. Anderson. The grating was used with its lines horizontal and its reflecting power, at 23°, compared with that of polished speculum. As was expected, a minimum was found in the curve (see Plate IV) at .71μ, where the relative reflecting power was 40%. Applying equation (1), the depth of the groove was calculated to be .38μ or 1/66,000 inch. (According to equation (2) H = .19μ or 1/132,000 inch.) In the curve there is a suggestion of a drop at 1.5μ , which may be the secondary minimum given by equation (2).

Reflection Experiments:

In the course of the work a variety of rough surfaces were tested - plate glass and plane speculum mirrors ground with the finest emery, glass roughened with the sand-blast and etched, afterwards gold-plated cathodically, smoked glass, also smoked glass coated cathodically with gold. The surfaces were tested visually for uniformity and coarseness by observing the angle at which they ceased to give a red image of the Nernst filament. As far as homogeneity is concerned, the simple method of grinding with fine emery was found to surpass any other process. Not only is uniformity ob-

tained over a wide expanse of surface (there being no patches obviously much rougher than the rest of the area), but in addition a matt surface of surprising fineness is easily obtained, especially if the emery be removed after a time, and the grinding continued with simply enough water to prevent sticking. When examined under the microscope, such surfaces exhibit no regular structure (which might give rise to interference effects. However, the presence of pits much deeper than the average seems unavoidable, and it is this which is thought to limit the reflecting power beyond 9μ. There is reason for believing that the topography of the humps and hollows in the case of smoked glass in some way makes such a surface better adapted to serve as an infra-red screen. Uniform films of smoke, varying in thickness from semi-transparency to opaqueness, are easily produced, but, as one might expect, their reflecting power, even at large angles, is very small. Some observations were made on smoked films which had been gold-plated cathodically, but they proved disappointing.

The type of surface sought was one whose reflecting power, at a given angle, is very low (say less than 10%) as far as 2μ or thereabouts, then rises as rapidly as possible to about 90%, remaining above that percentage for all longer waves. After silver plating such a matt surface, two reflections from it would leave 1% or less of the short waves, and 80% or more of the waves longer than 2μ, - in other

words, would prove an ideal infra-red screen. It is clear that the curve for a rather coarse surface will rise less rapidly than that for a smoother surface at the same angle of incidence, and it is probable that a coarse surface at a large angle will serve as well as a smoother one at a small angle, supposing that the greater foreshortening in the former case makes up for the greater depth of pits. Yet it must be remembered that all ground surfaces are extremely irregular, and since it is not possible to apply the simple theory referred to on page I, it cannot be predicted what combination of angle of incidence and depth of pits will turn out to be the most satisfactory.

The surface whose reflection curves appear in plate V was on the whole the most satisfactory one investigated. In preparing this surface two pieces of ordinary plate glass (1/4 in. thick) were ground together, using the finest Bausch & Lomb emery. After a few minutes grinding, the emery was washed off and the grinding continued with water alone. In this fashion a surface was produced which gave a red image almost at normal incidence, and which was far smoother and especially more uniform than any prepared by etching or with the sand-blast. It will be noticed that the curves are all very steep, those at 70° and 75° being especially satisfactory because they begin low (6.5 % at .9μ and 20% at .75μ respectively), and rise sharply to

76% and 84% at 4μ, approaching 100% thereafter. (Here the reflecting power is referred to that of polished glass, but it has been well established by the other experiments that the material itself plays no role. By silver plating this rough surface, curves would be obtained like those drawn, but with reflecting power in absolute measure.) There is a curious slight depression in all the curves at 8μ. Though very little energy is reflected from glass in this portion of the spectrum, and readings are therefore obtained with difficulty, repeated measurements, however, confirmed this drop to within 2 or 3%. This effect may be due to multiple reflections at the ground glass surface. Plate VII gives the curves for a coarser surface which was silver plated, and for a very fine speculum surface. The former was compared with a polished plate of glass silvered simultaneously with the rough one; the latter was compared with polished speculum. The curves were not satisfactory.

Plate IX is for a surface almost as smooth as the one first described, which was coated cathodically with platinum and compared with polished glass platinized simultaneously with the rough piece. These curves are the most regular ones obtained. As the angle of incidence is increased from 25% to 84%, the curves ascend more and more steeply. However, judged as an infra-red screen, this surface is less satisfactory

than the smoother one first described.

Several surfaces prepared with the sand-blast and afterwards etched were tried, but gave disappointing results. The finest and most uniform of these was gold plated and compared with polished gold.(See plate VIII). These surfaces were kindly furnished by Professor R. W. Wood. Since surfaces blown and etched in this manner consist of minute hollows resembling so many small concave mirrors *, it is of some importance to establish the nature of their reflection as compared with the irregular surfaces produced by ordinary grinding. Anything approaching regularity of structure might give rise to a minimum at a certain definite wave-length owing to interference. Nothing like this was noted. Furthermore the curves obtained resemble those taken before the surface was gold plated, hence the topography of the surface was not altered appreciably by the addition of a layer of gold.

Transmission Through Rough Surfaces:-

Owing to the fact that most transparent substances such as glass, quartz, Iceland spar, etc. show absorption bands

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* Lord Rayleigh, loc. cit.

not very far out in the infra-red, it is evident that a matt surface can be of only limited use as a transmission screen. Rock salt, being transparent as far as 15μ, was chosen for the following experiments.

It was found that very striking effects can be obtained simply by breathing on the polished rock salt surface. Plate III gives the transmission of a plane parallel crystal roughened in this manner. Since the light must penetrate two matt surfaces, the curves are all steeper than they would be if only one face of the crystal were rough. This plate when held before an incandescent lamp transmitted only the blue-green, - a curious phenomenon of interference exhibited beautifully by films consisting of minute bubbles,* and by gratings whose central images are colored. Viewed under the microscope this rock salt crystal showed a perfectly regular structure resembling that of a honey-comb.

Plate III gives also the curves for a crystal with coarser surfaces and ~~also~~ for one absolutely opaque. On the whole the curious surface described above seems to make a better infra-red screen than any of the rough surfaces used in the reflection work. It is the author's opinion, however, that ground glass surfaces smoother

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* Wood's Optics, p. 253 (new edition)

than those described above, but prepared in the same way, and afterwards silver-plated, will make fairly satisfactory screens for eliminating waves shorter than 1μ and retaining all the longer waves with but slightly reduced intensity. From the curves given in Plate V, different points were selected on the 75° curve, and the ordinates squared, to show the effect of two reflections. A curve was also drawn for a fixed wave-length between reflecting power and angle of incidence. (See Plate VI).

Part II.

Reflection Curves for Glass, Quartz and Iceland Spar in the Regions of Metallic Reflection at Various Angles of Incidence .

While engaged in the reflection experiments on ground glass, it seemed desirable to take the reflection curve of polished glass, for comparison with the results of other observers. Since it happened that the first curve was taken at 54° , it seemed advisable, in view of the very curious result obtained (see Plate X), to pursue the experiments further, using different angles of incidence and other substances which like glass exhibit metallic reflection. The deflections obtained using polished surfaces of glass, quartz and Iceland spar were divided by those obtained when a silver mirror

was substituted. By a direct method the reflecting power of the silver was obtained at several points in the spectrum, and the reflecting powers referred to above multiplied by the reflecting power of the silver. Since the same comparison silver mirror was used for all the curves, they must be consistent. Furthermore, at least half the curves were obtained using both parallel and converging light. There was good agreement between the two.

Resolution of Bands of Metallic Reflection at Large Angles of Incidence:

If the reflection curves for glass are closely scrutinized, it will be clear that the net result~~s~~ of increasing the angle of incidence is to bring out a component band near 8.4μ, which grows as the angle increases and suppresses the main band at 9.4μ for angles greater than 70°. This new band, scarcely discernible in the 23° curve (though attention has been drawn to it by Coblentz), is thought to have some connection with the 8.5μ quartz band, just as the 9.4μ maximum in the glass curves certainly bears some relation to the 9μ quartz band. (Or, since SiO_2 is a constituent of glass, one ought to say that the maximum in the glass curves, whether considered single or double, is due to both the 8.5μ and 9.5μ bands characteristic of quartz). Now it is known that silicates in general show only one maximum near 9μ (See Pfund *, ~~Coblentz**)~~. It may turn out that other silicates besides glass

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* Pfund. Astrophysical Journal XXIV, 1, July 1906, p. 32

~~** Coblentz.~~

will show the maximum doubled at large angles of incidence.

In the case of quartz, the 84° curve suggests that the 8.5μ band is really double; while the curves for Iceland spar (Plate XII) indicate that the 6.7μ band is triple. It will be noticed that the bulge at 6.4μ on the short-wave side of the maximum is absent entirely for angles of 60° or less. Owing to the enormously sharp rise in reflecting power which occurs between 6.25μ and 6.7μ, it would be very difficult to detect any bulge in this interval when the angle is less than 60°. On the other hand, the bulge on the long wave side of 6.7μ is much in evidence even at 23°.

In the case of glass, it seems that there are two types of resonators in the atom, the effect of the one type (i.e. those giving rise to the 8.4μ band) completely overshadowing that of the other type at small angles of incidence, whereas at the larger angles the latter becomes predominant. It is curious that this phenomenon should depend on the angle of incidence. It is not probable that polarization plays much of a role, as however might be suspected from the appearance of the glass curve for 54°, which is near the angle of maximum polarization. Such an effect might depend , in the case of crystals * , on the direction of the optic axis with regard to the azimuth of the reflected beam. Curves taken with the crystal

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* Pfund. loc. cit. p. 29, and Nyswander, Phys. Rev. 28, 1909, p.291

of Iceland spar (two different crystals were used in the course of the work) rotated through 90° and 180° with regard to the original position failed to show any difference in the curves.

Nyswander* has mapped the reflection curves for the two crystals calcite and aragonite, polarized in different azimuths, but his results shed no light on the question discussed above. Moreover, Nyswander polarized the light before sending it through his spectrometer. Owing to a possible polarization at the surface of the rock salt prism, it seems advisable, if results of value for comparison with theory are sought, to polarize the monochromatic light after it ~~is used~~ emerges from the spectrometer.

The results described in this paper are meant to be only preliminary in their nature, and it is to be regretted that certain features of the method employed lay it open to criticism on the score of polarization effects, etc. as mentioned above. However, there are several points standing out clearly in all the curves which are so consistent that they merit serious consideration. In the first place, the minimum which is noticed on the short-wave side of the maximum is accentuated, and very much deepened by an increase in the angle of incidence. One notices this clearly on the long-wave

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* Nyswander, loc. cit.

side of the maximum also, at very large angles. In the case of quartz this depression occurs at 9.6μ for 84° , is absent entirely in the 60° curve, and appears only as a gentle bend in the 78° and 81° curves . A similar depression crops up even in the case of the last maximum (12.5μ), coming at 12.7μ . The behavior of these curves at 7.5μ, and of the glass curves at 8μ is strikingly similar. Now if one remembers that the effect of increasing the angle of incidence is to steepen the rise on both sides of the maximum in the manner described, by accentuating the depression on either side of the maximum, it is not hard to see that if any given band of metallic reflection (e.g. the glass band at 9.4μ) is in reality double, this fact may appear in the curves for large angles even though it is scarcely discernible in the case of small angles of incidence. Of course, this does not explain why the 8.4μ band plays such a predominant role at the expense of the original 9.4μ band in the case of glass at angles greater than 70°. The fact that the curves for glass, a non-crystalline substance, behave in much the same way as those for the crystals of Iceland spar and quartz, lends weight to the claim that the effect is independent of polarization.

It is planned to continue the experiments, using plane-polarized monochromatic light (i.e. light polarized after its

emergence from the spectrometer) as suggested on page 21. By means of such a method it should be possible to obtain results of great theoretical value. If the optical constants μ and k of such crystals are really independent of the angle of incidence, then measurements at different angles ought to be sufficient for calculating them; whereas this would not be true if there is some connection (i.e. in the region of metallic reflection) between μ, k and the angle of incidence. The curious depression at 8μ for glass and 7.5μ in the case of quartz is thought to have some bearing on the decrease of μ which is known to occur when an absorption band is approached from the short-wave side. Indeed the glass curves for angles greater than 70° might be mistaken for the dispersion curve of a substance possessing one absorption band. It may be that for these angles the reflecting power is a linear function of the refractive index. Yet this is certainly not true for angles less than 70°.

Summary.

I. A study of the reflecting power of matt surfaces has been made at various angles of incidence, for the purpose of finding a suitable infra-red screen.

2. Roughened crystals of rock salt were found to transmit the light in almost an ideal way, eliminating practically all waves shorter than 1μ , and letting through waves longer than 3μ with but little decrease in intensity. The reflection screens are preferable to the transmission screens because they give curves just as steep as those obtained by transmission, and in addition are good for an unlimited range of wave-lengths in the infra-red.

3. Increasing the angle of incidence was observed to effect a profound and curious change in the reflection curves for polished glass, quartz, and Iceland spar, which may best be described as a quasi- resolution of the bands of metallic reflection.

4. A description is given of an infra-red spectrometer which is believed to possess better definition and greater resolving power than is usually furnished by instruments of similar type.

In conclusion, the writer wishes to thank all those who have aided him in this investigation. He is under obligations to Professor J. S. Ames, for advice and criticism, and to Dr. J. A.

Anderson, for the loan of gratings and mirrors. The mechanical excellence of the spectrometer is due to the skill of Mr. C. M. Childs, one of the mechanicians in this laboratory. To Dr. A. H. Pfund, who suggested and directed the work, the writer is more than grateful for his ingenious suggestions, inspiring criticism, and willingness to aid at all times.

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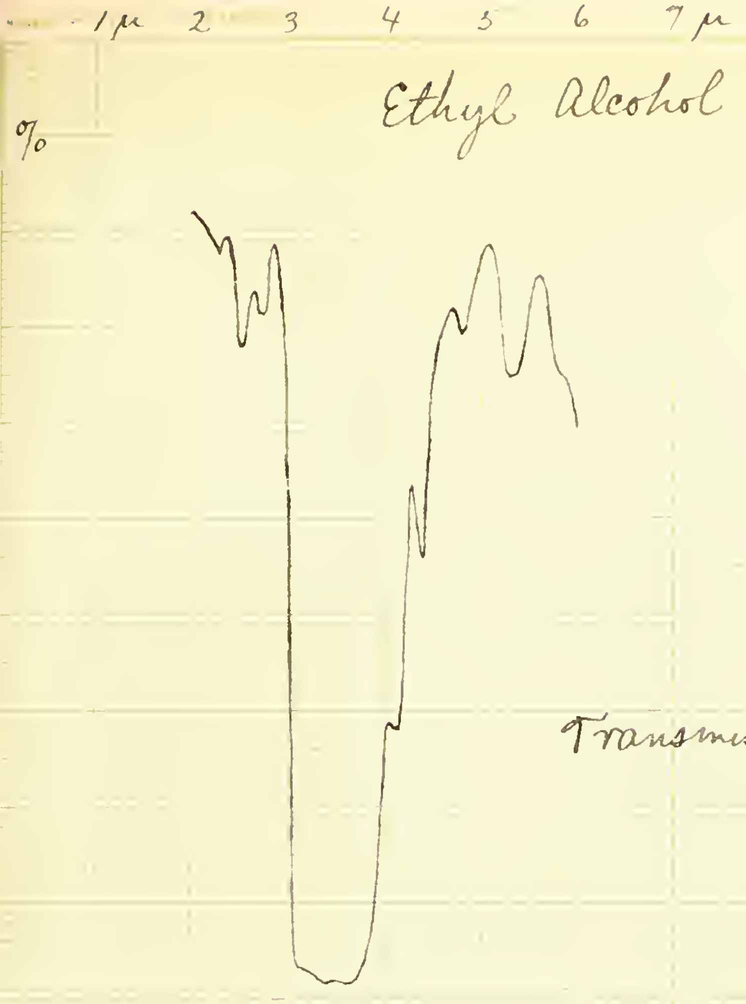
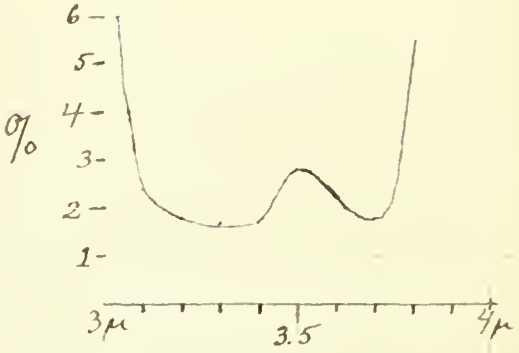
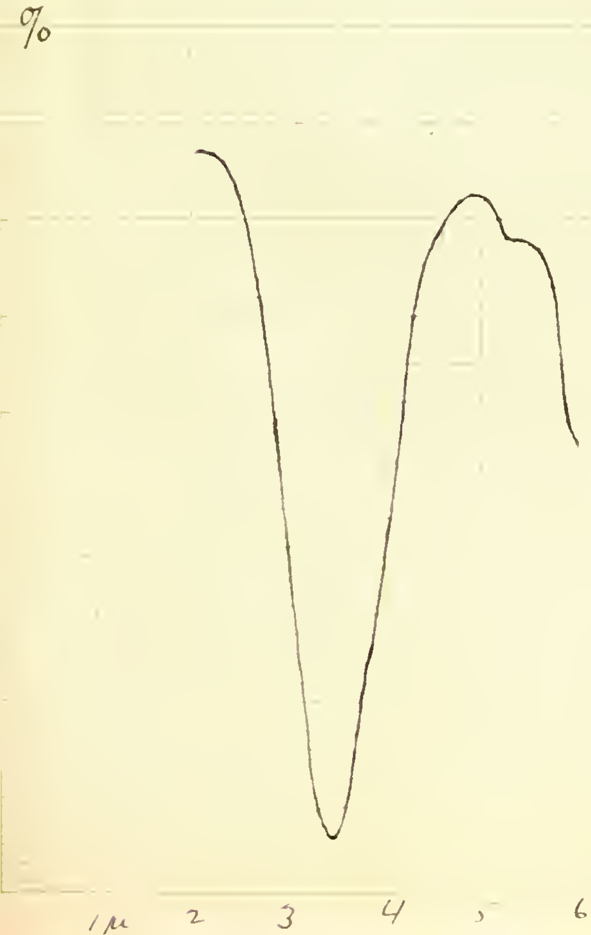
PLATE I



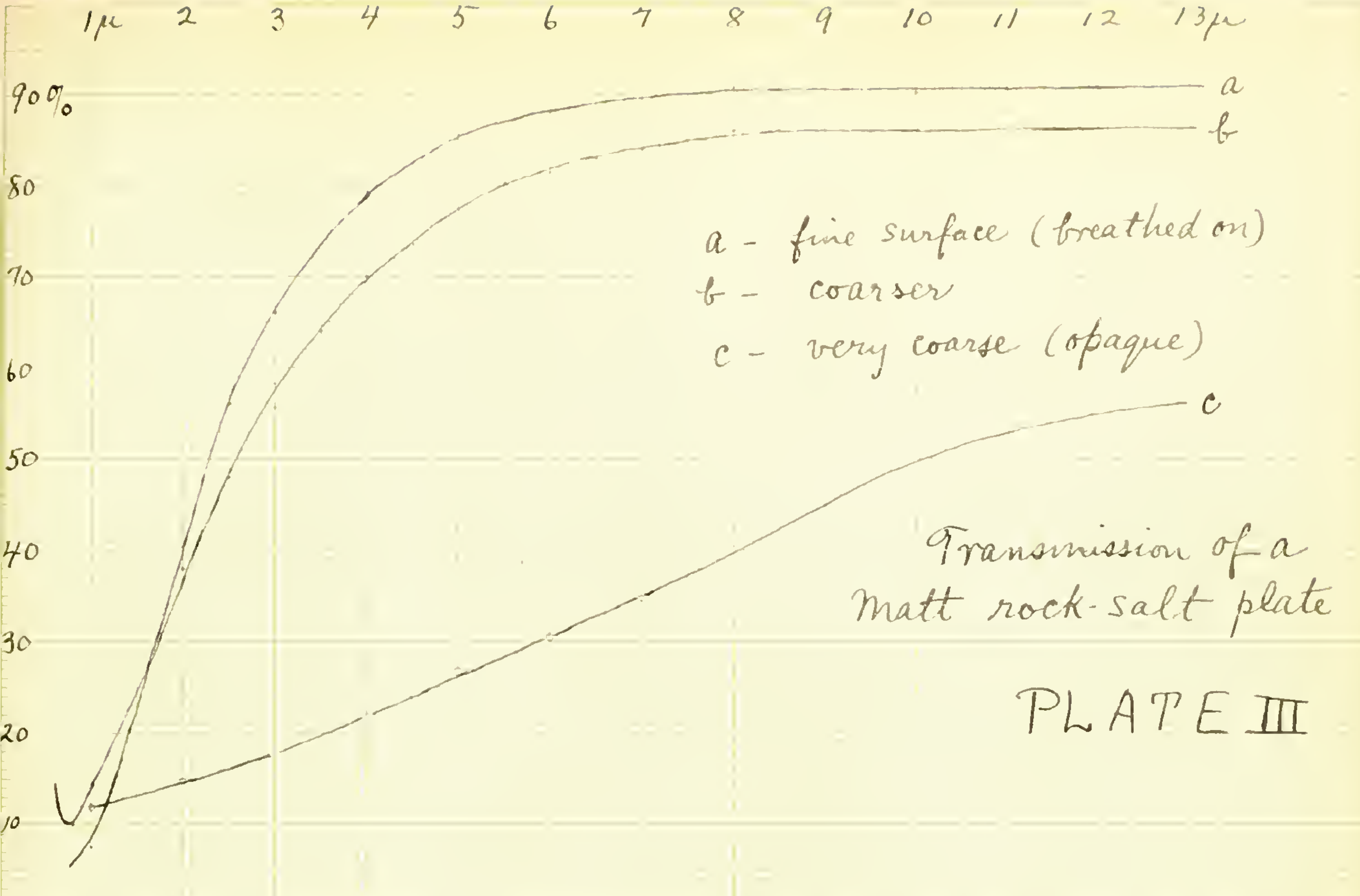


Transmission of Ethyl Alcohol
film 0.1 mm. thick

PLATE II

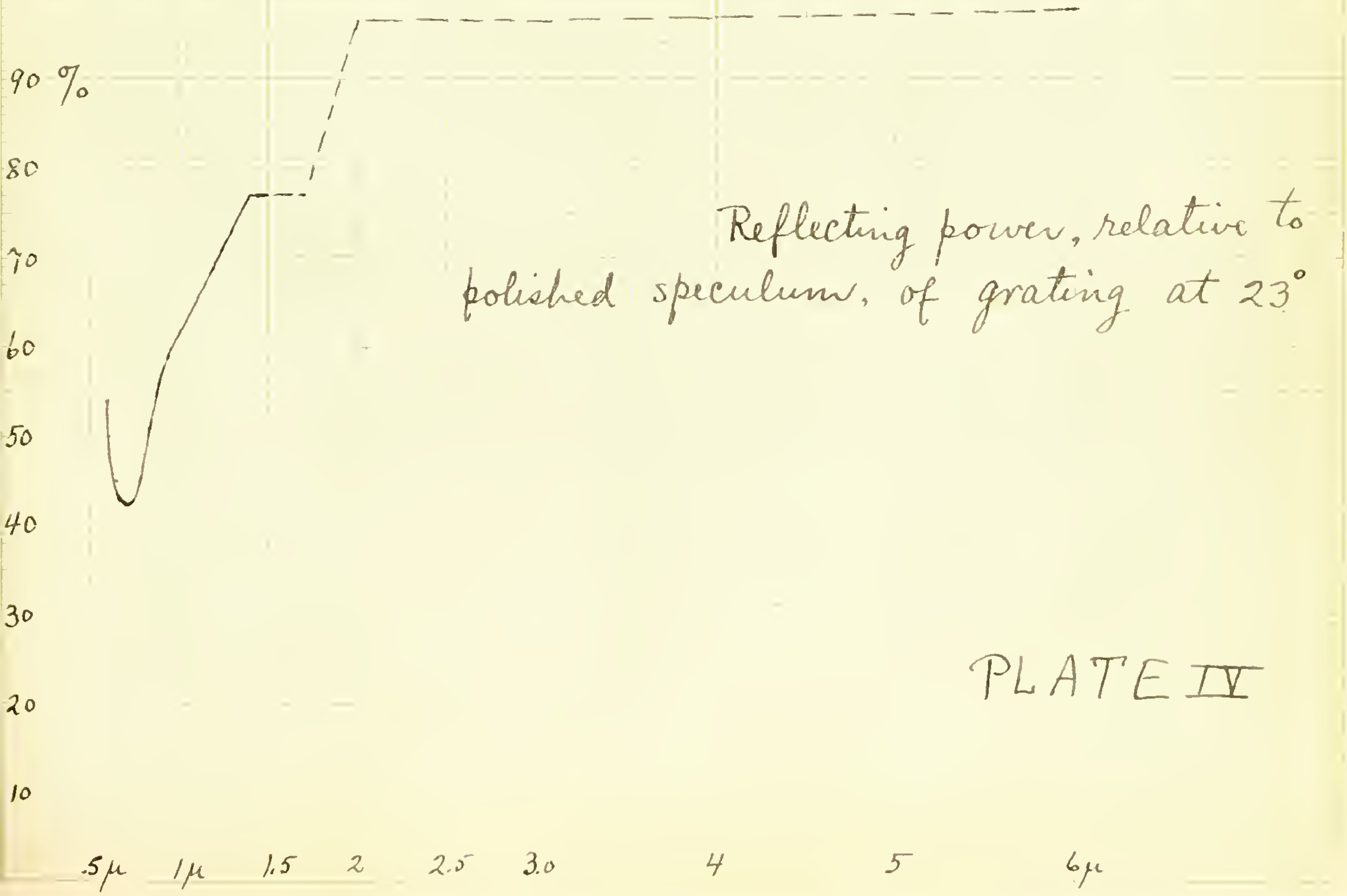


Transmission of Ethyl Alcohol.
film .01 mm. thick,
according to
Coblentz.



Transmission of a Matt rock-salt plate

PLATE III



Reflecting power, relative to polished speculum, of grating at 23°

PLATE IV

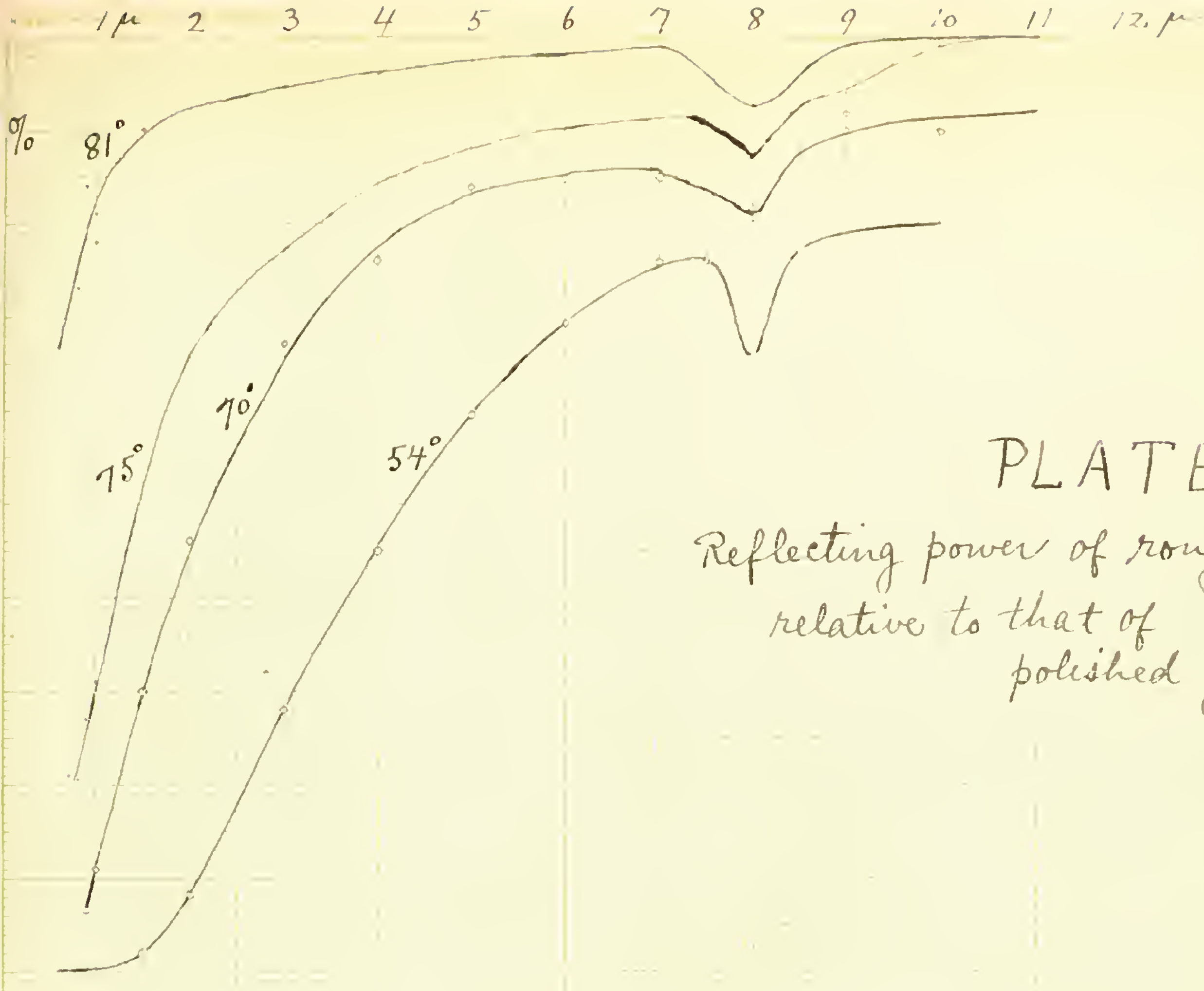
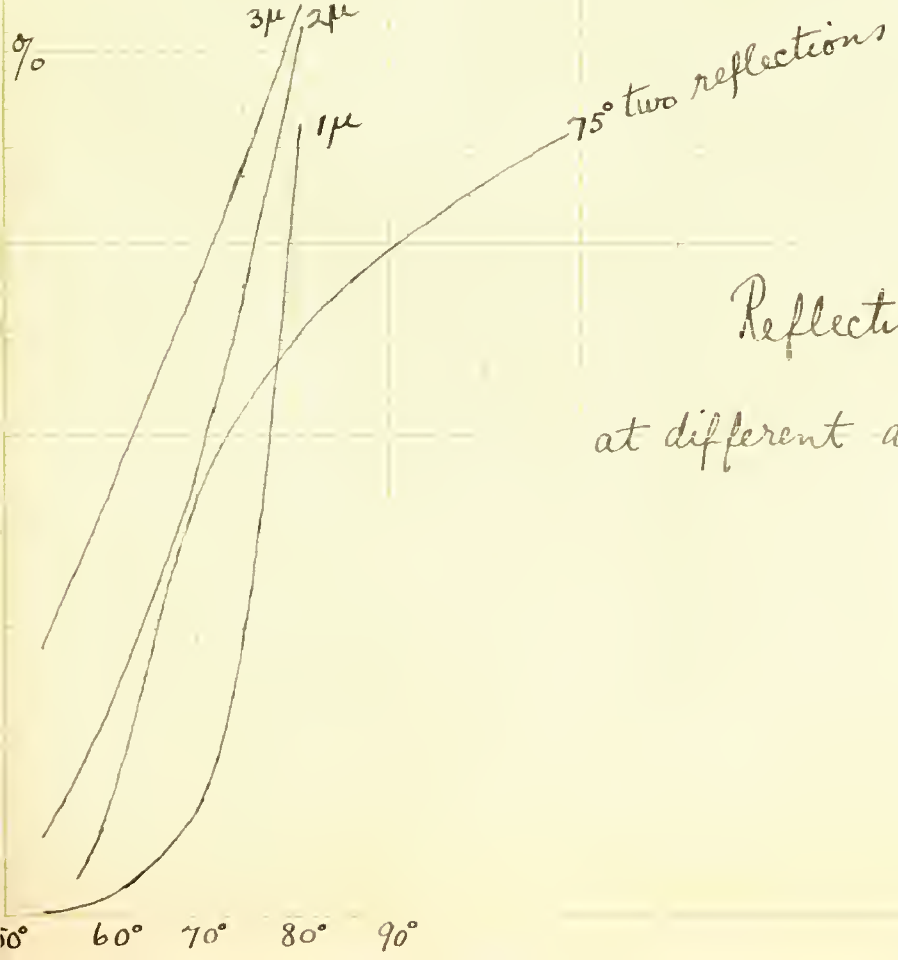


PLATE V

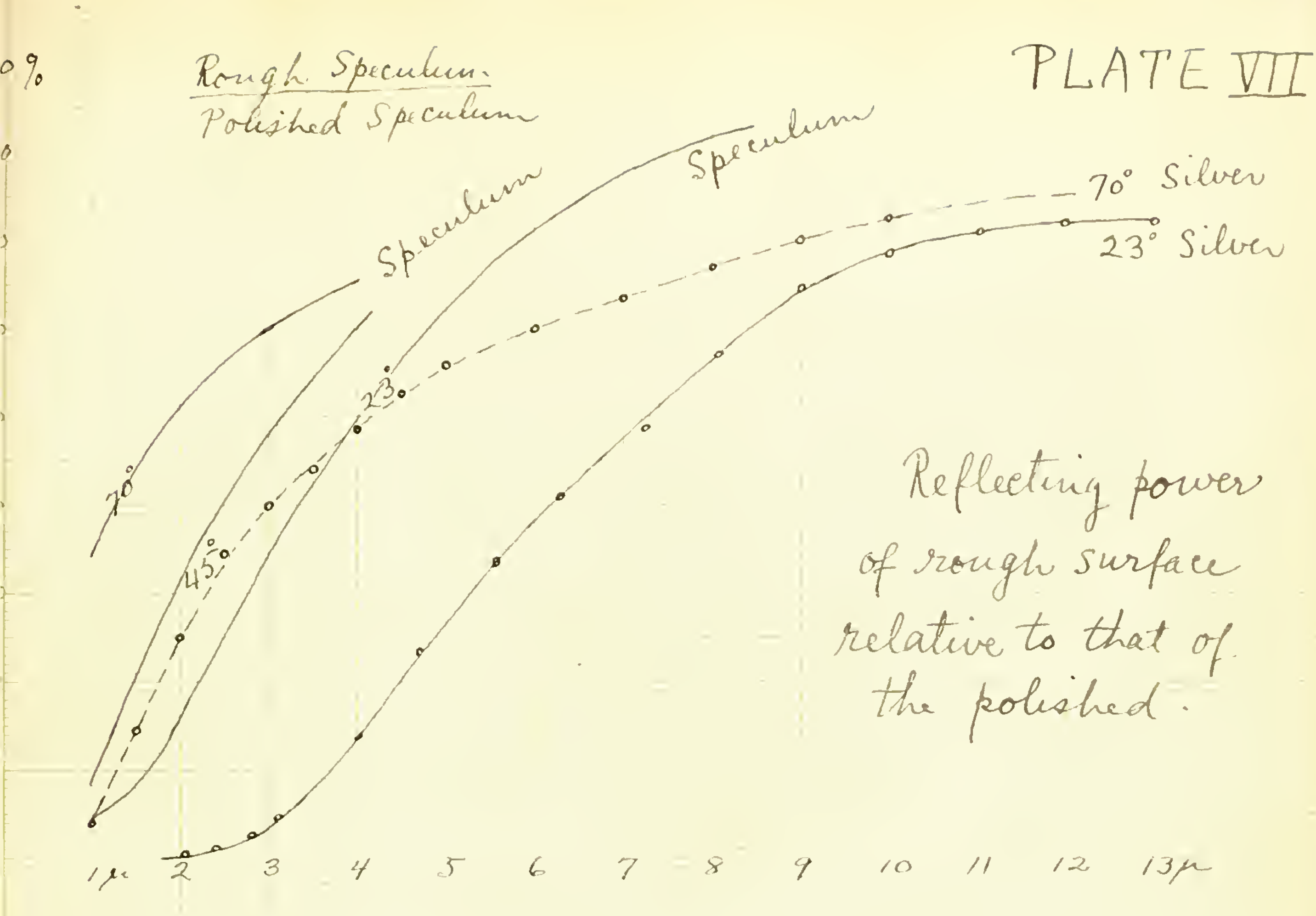
Reflecting power of rough glass,
relative to that of
polished glass.



Reflecting powers for a fixed
wave-length,
at different angles of incidence.

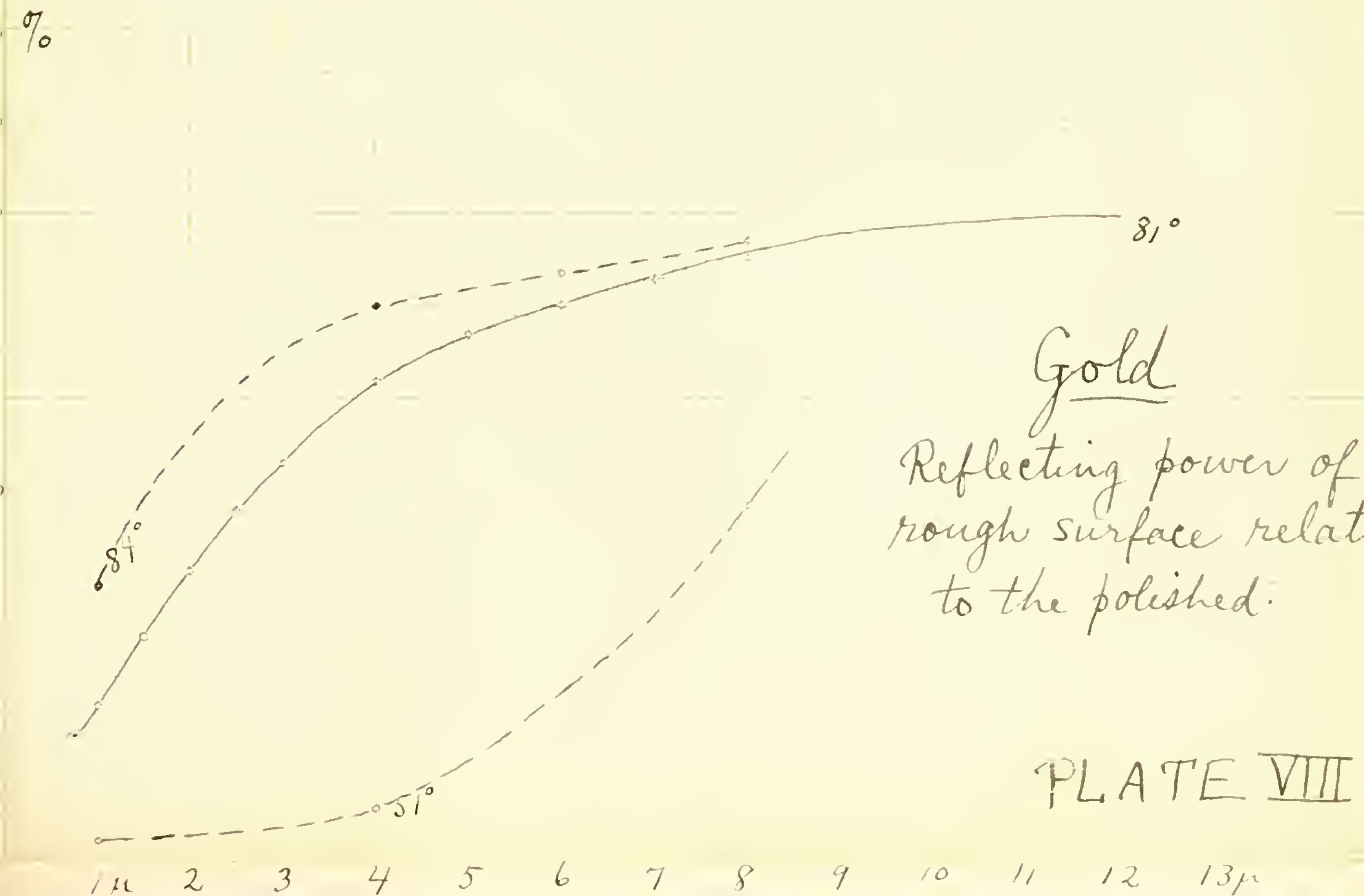
PLATE VI

PLATE VII



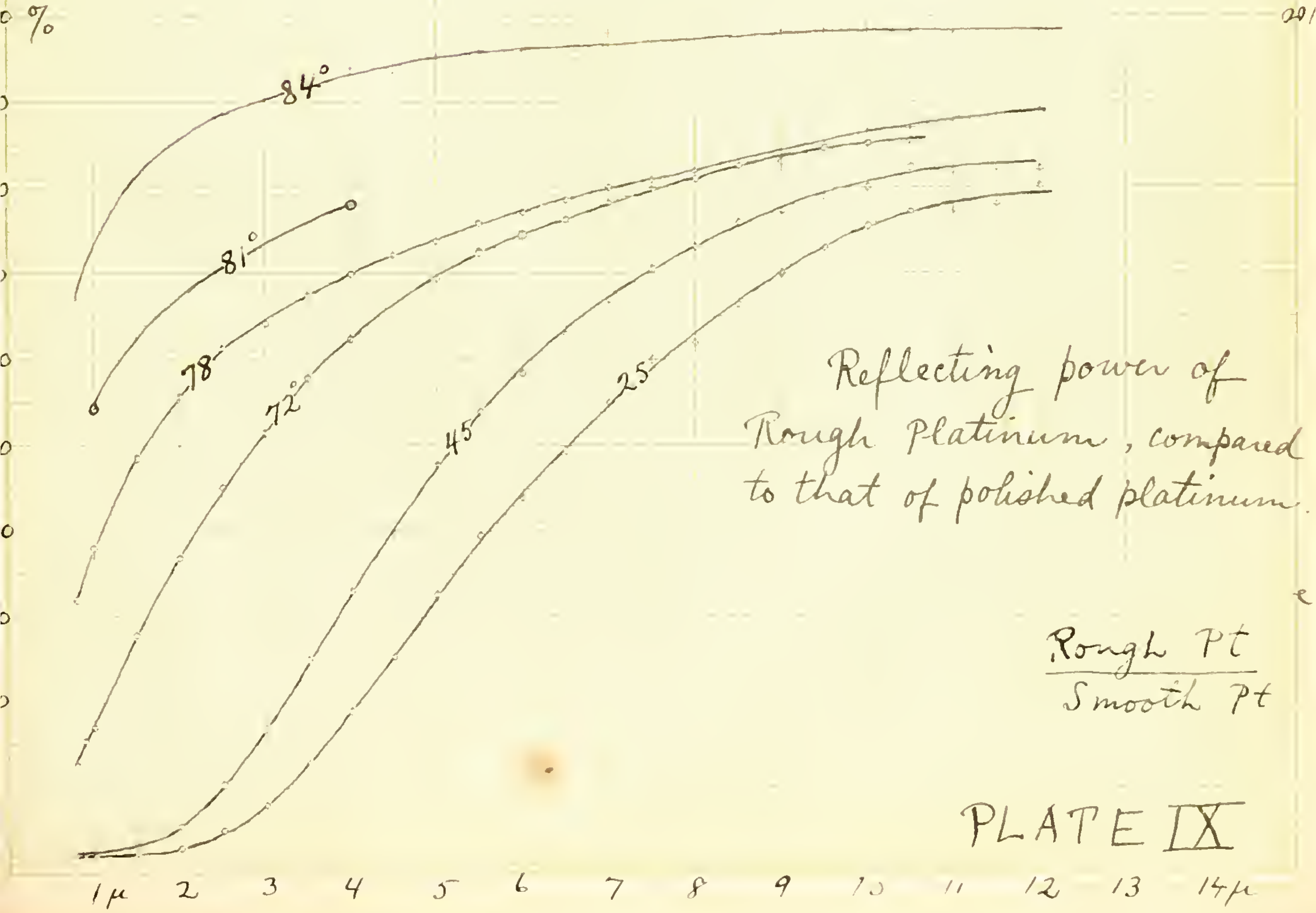
Reflecting power of rough surface relative to that of the polished.

Gold



Reflecting power of rough surface relative to the polished.

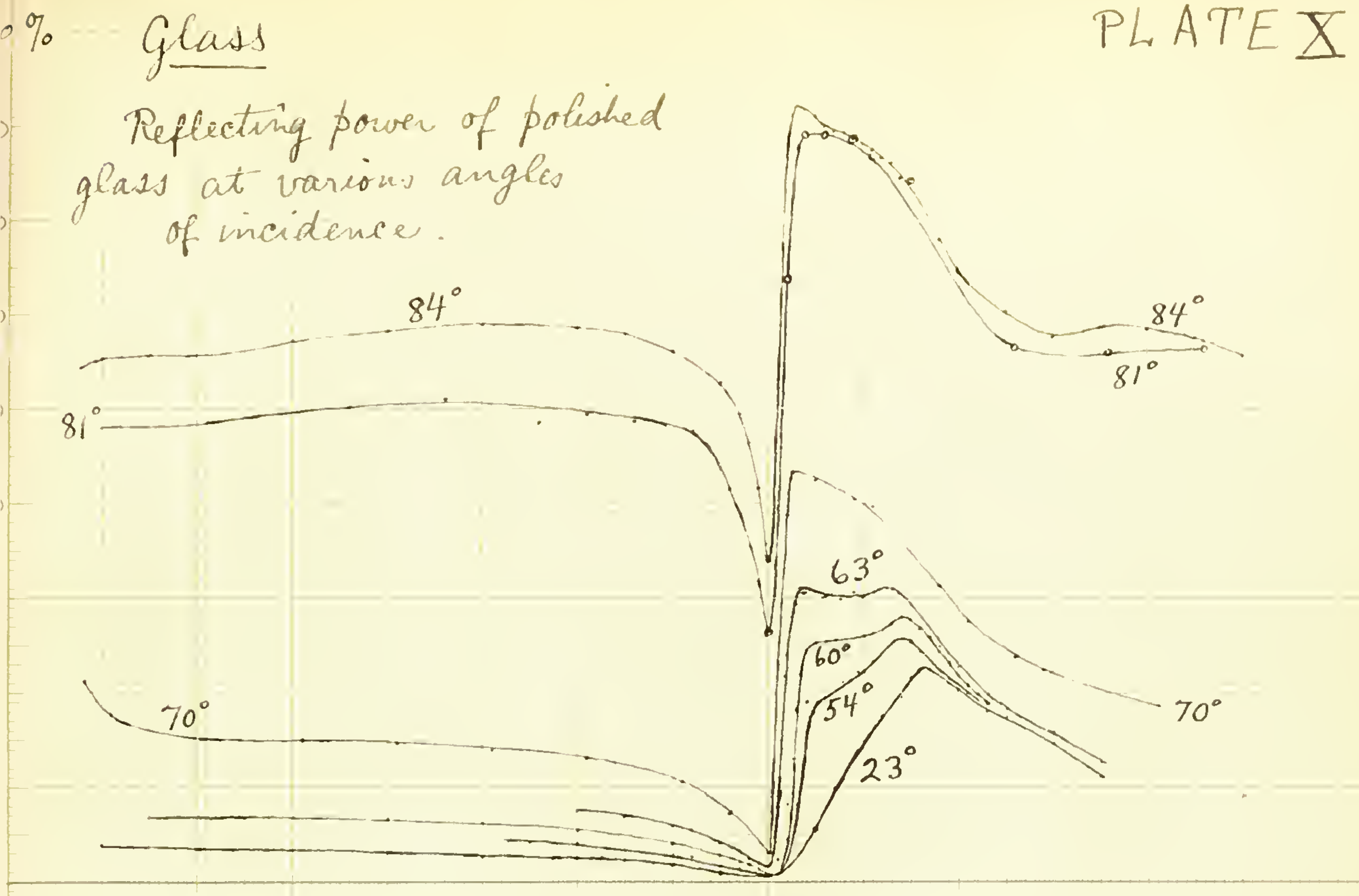
PLATE VIII



Reflecting power of Rough Platinum, compared to that of polished platinum.

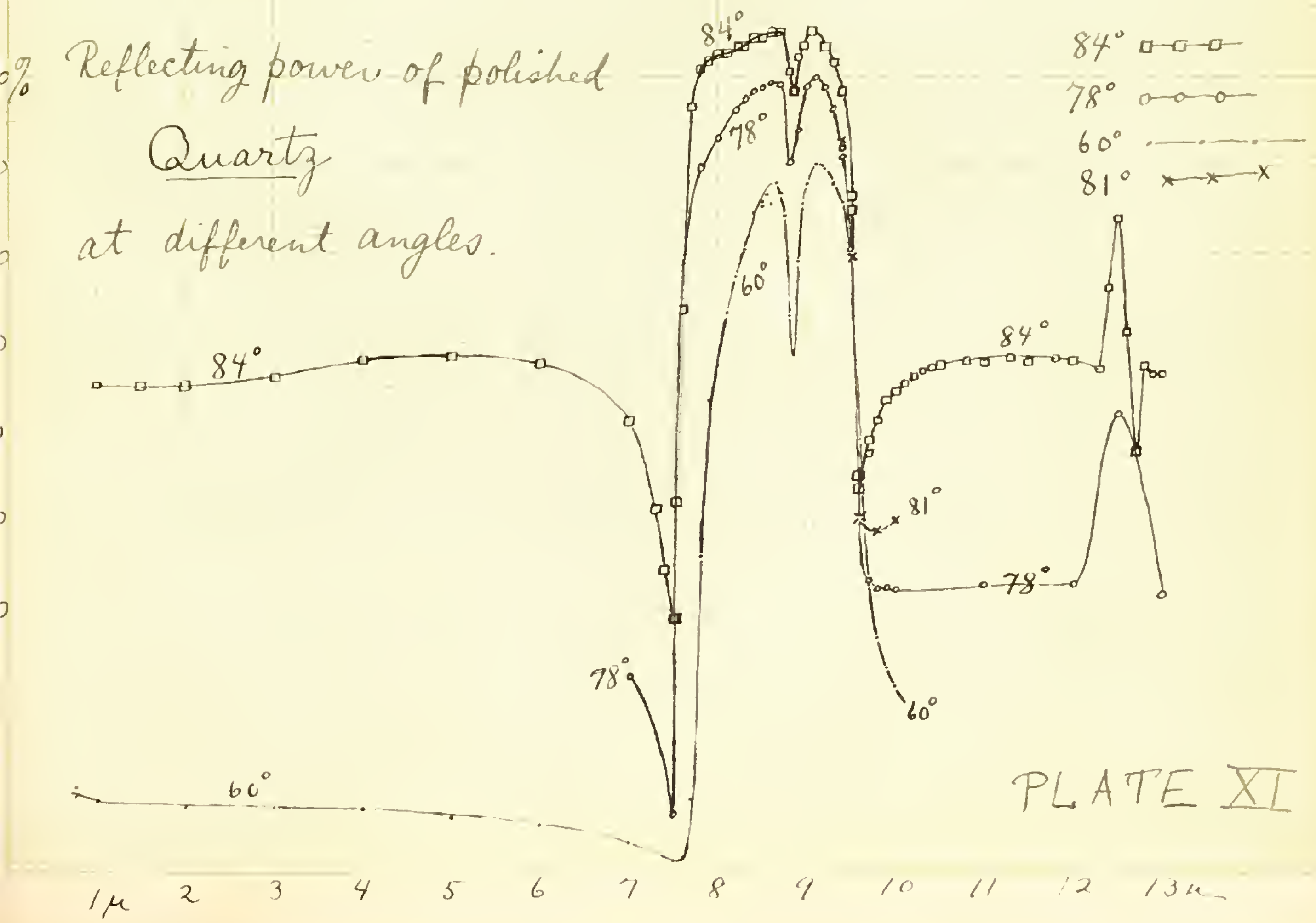
PLATE IX

PLATE X



Glass

Reflecting power of polished glass at various angles of incidence.

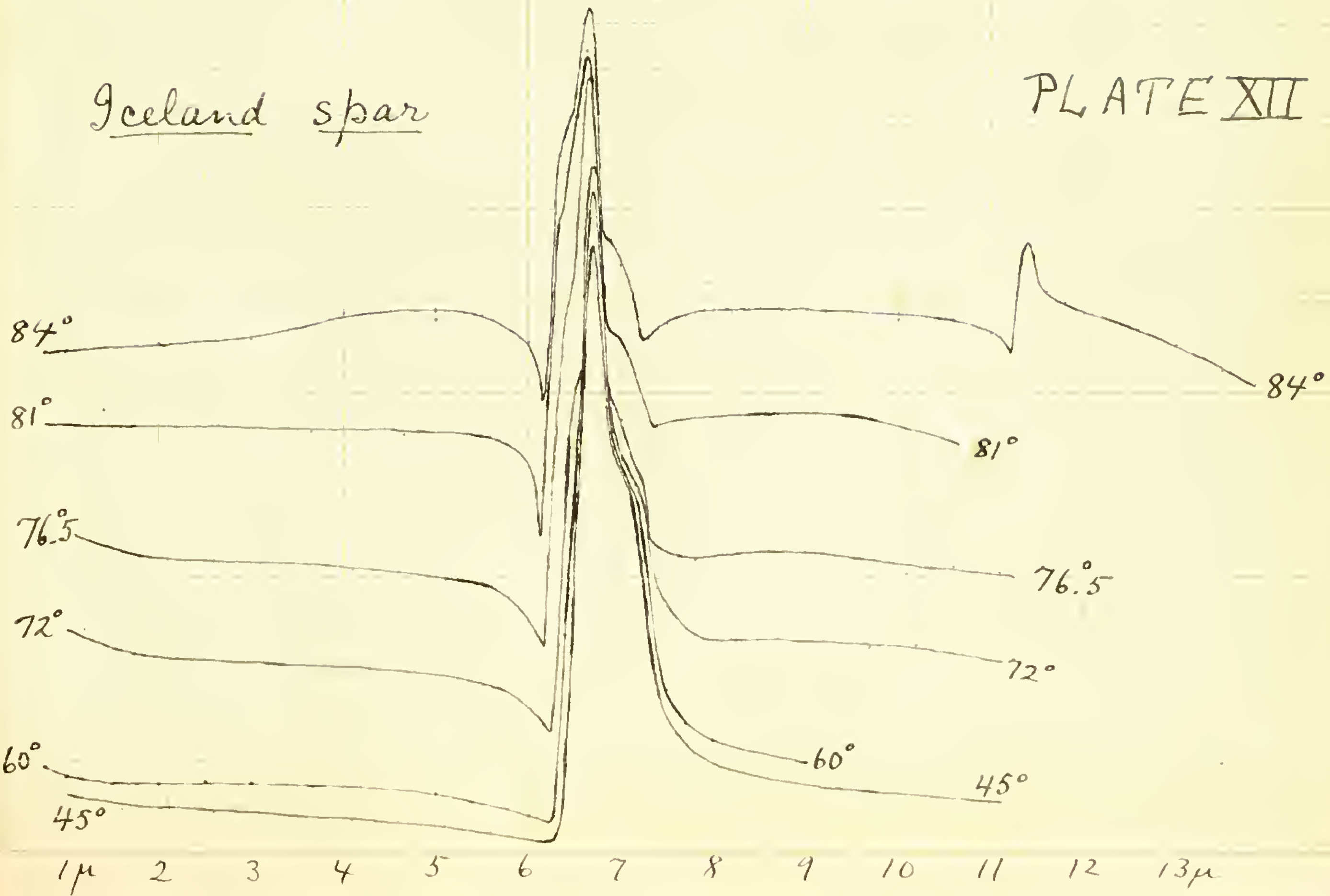


Reflecting power of polished Quartz at different angles.

PLATE XI

PLATE XII

Iceland spar



Biography.

Arthur Feddeman Gorton, son of William Curns Lawrence Gorton and Anna Feddeman Gorton, was born September 17, 1891 in Baltimore, Maryland. He received his preparatory education in the public schools of that city. He entered the Johns Hopkins University in 1908, and received the degree of Bachelor of Arts in 1912. The same year he entered the Department of Physics as a graduate student, taking Physics as the principal subject, Astronomy and Celestial Mechanics as the first subordinate and Mathematics as the second subordinate. In 1914 he was admitted to the degree of Master of Arts. During the years 1908-1910 and 1911-1914 he was Hopkins Scholar, and for the year 1914-1915 Fellow in Physics. He has attended graduate courses given by Professors Ames, Wood, Whitehead and Anderson in Physics and by Dr. Cohen in Mathematics.

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